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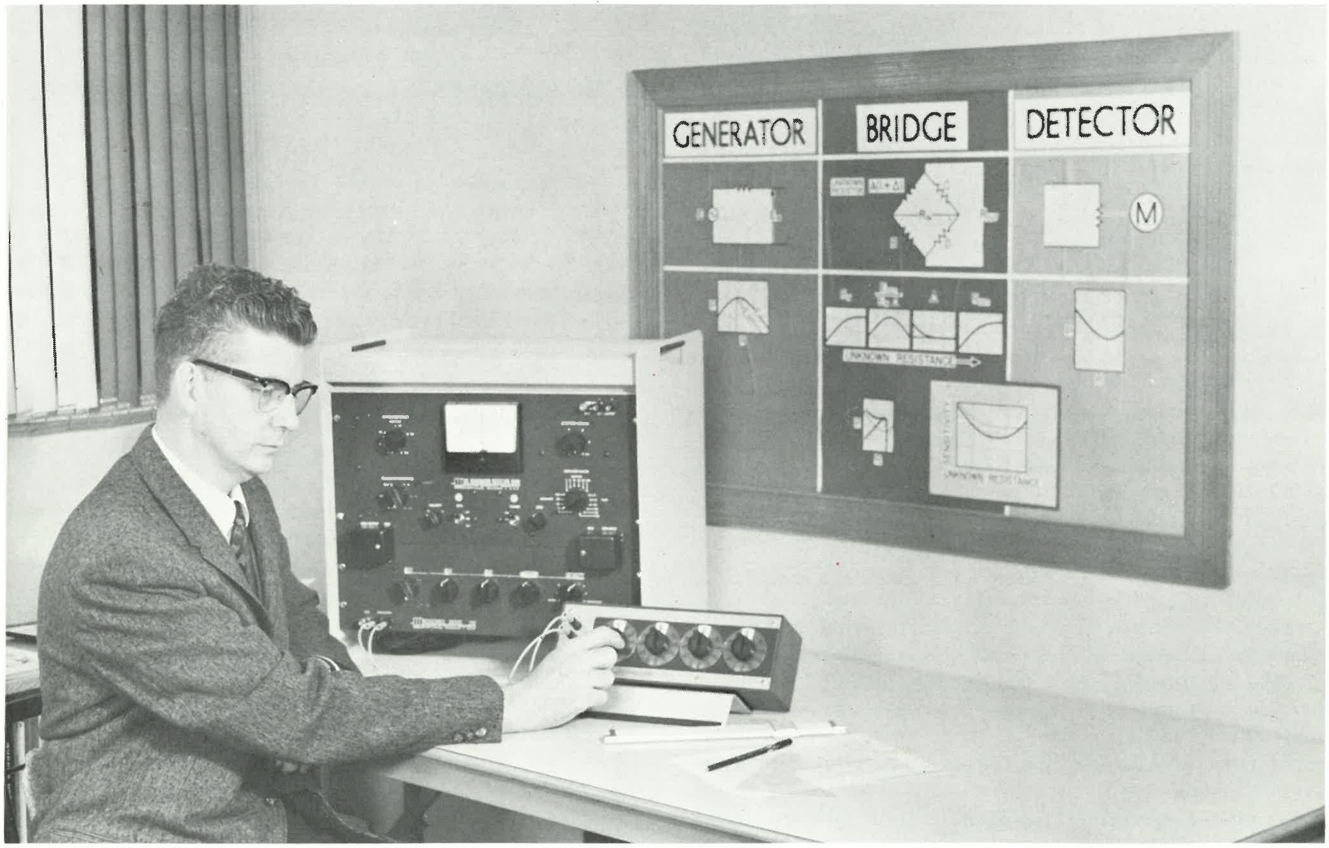

BRIDGE PERFORMANCE GRAPHS

INTRODUCTION

A graph of bridge output for rated accuracy and resolution can be compared with a graph of detector sensitivity to determine the precision of a proposed measurement.

SENSITIVITY

Some bridge measurements give large null detector deflections with the smallest changes in setting. Other measurements are so sluggish that many dial divisions of bridge resolution must be used to give an observable deflection. The measure of this response is called bridge sensitivity. The null indicator deflection divided by the bridge unbalance gives a numerical measure of this sensitivity.

PRECISION

Sensitivity is only one of the limits to the precision of a bridge measurement. Precision is also limited by the accuracy and resolution of the bridge. A well-designed bridge is as accurate as component stability and precision manufacturing tolerance will permit. The bridge resolution is designed to measure differences as small as the accuracy will justify. After the accuracy and resolution for the bridge are determined, the generator and detector are chosen to give adequate bridge sensitivity for all measurements. When we have a component to measure, it would be convenient to have a simple way to find out whether any particular combination of bridge and detector will have sufficient sensitivity to make the measurement to the precision that we require. This issue of Design Ideas is going to discuss a graphical method of specifying bridge outputs and detector sensitivities so that we can readily analyze their combined performance for any measurement. We will illustrate this method with some specific bridge examples.

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PERFORMANCE GRAPHS

The output of an unbalanced bridge can be represented by an equivalent circuit consisting of a constant voltage source in series with a resistor (Thevenin's Theorem) or by a constant current source in parallel with the same resistor (Norton's Theorem). Such an equivalent circuit can be plotted as a single point in co-ordinates of voltage or current versus resistance. We make these plots on a paper which has co-ordinates of log power versus log resistance with diagonal co-ordinates of log voltage and log current. On this paper the open-circuit voltage, short-circuit current and internal resistance of the source all intersect at this one point. The output of an unbalanced bridge (a balanced bridge has no output) can be considered as such a source and, therefore, can be plotted as a point. A plot of the locus of points for various bridge settings gives a complete picture of the bridge output when measuring various resistance values. To determine the bridge output, we need to choose a specific amount of bridge unbalance and a specific bridge generator. Then we can find the output for different impedances to be measured and plot the locus of these points on our graph paper to represent the bridge output for all values of impedance that it can measure. We are particularly interested in these plots for an unbalance equal to the accuracy or the resolution specified for the bridge.

Next we need to determine how a given detector will work with this bridge. We can plot sensitivity curves for the detector on the same co-ordinates. A detector curve consists of a locus of points representing all of the sources which would drive the detector to a specified deflection.

We can determine the minimum detectable deflection for a given detector and plot such a detector curve on a bridge output graph. Then we can tell at a glance whether the bridge is putting out a large enough signal to produce a visible deflection on the detector. These plots of bridge output and detector sensitivity include the whole range of impedance values that the bridge can measure and show which values are limited by accuracy or resolution, and which by bridge sensitivity.

From the graphs we can determine what corrective measures to take if we need to increase the precision of our measurements. Since the bridge output voltage is directly proportional to its input voltage and also directly proportional to the amount of bridge unbalance for small unbalances, we can use our curves to determine quantatively the amount of bridge unbalance which we could detect or the amount of additional input voltage which we should supply to the bridge for a desired measurement.

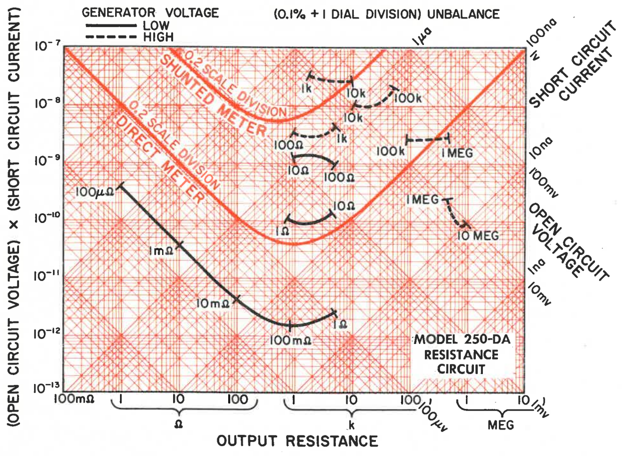
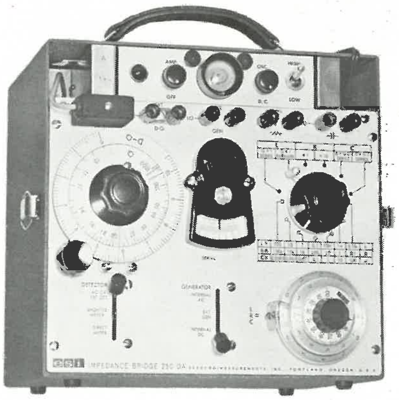


Figure 1.

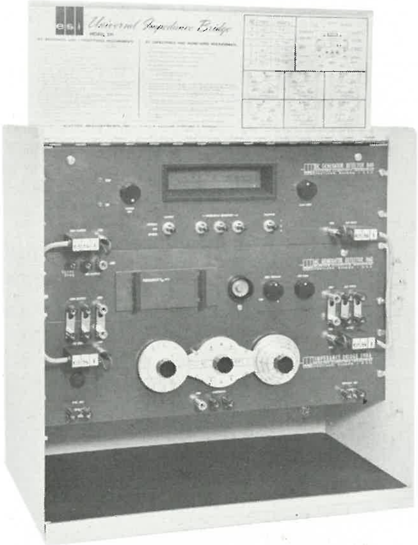


MODEL 250-DA UNIVERSAL IMPEDANCE BRIDGE

BRIDGE PERFORMANCE — ESI MODEL 250-DA

The first example of the bridge and detector graph, Figure 1, is the ESI Model 250-DA Universal Impedance Bridge. The graph shows the resistance bridge performance. Each point on the bridge curves represents the intersection of open-circuit voltage, short-circuit current and output resistance for a particular value of resistance being measured. For these curves the bridge's internal power supply is used and the bridge is unbalanced by the amount equal to its specified accuracy of ± (0.1% + 1 dial division), (0.1% accuracy, 1 dial division resolution). The solid bridge curves are for the "LOW" setting of the bridge generator. The dotted curves are for the "HIGH" setting. The detector curves represent values of open-circuit voltage or short-circuit current and generator resistance for sources which would deflect the bridge galvanometer 1/5 of one scale division. Detector graphs are plotted for both the shunted meter and direct meter conditions.

For example, if we are measuring a 10 ohm resistor using the 10 ohm to 100 ohm range we have about five times as much voltage available with a 0.1% unbalance as we need to deflect the galvanometer 0.2 scale divisions. Therefore, we can either get approximately 1.0 divisions deflection with 0.1% unbalance, or we can detect a 0.02% unbalance with the 0.2 scale division deflection.



MODEL 291-A IMPEDANCE MEASURING SYSTEM

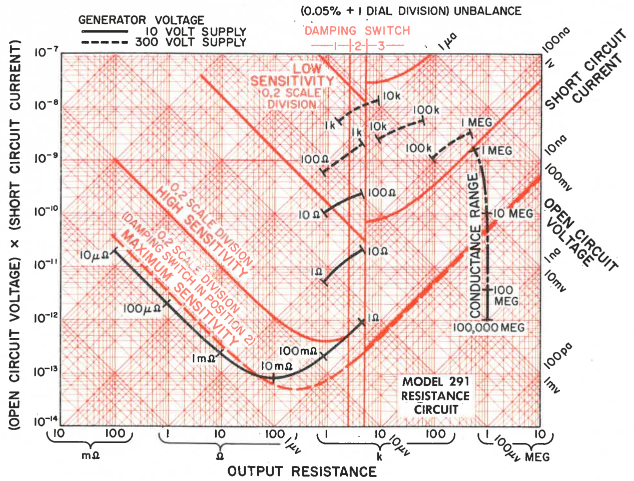


Figure 2.

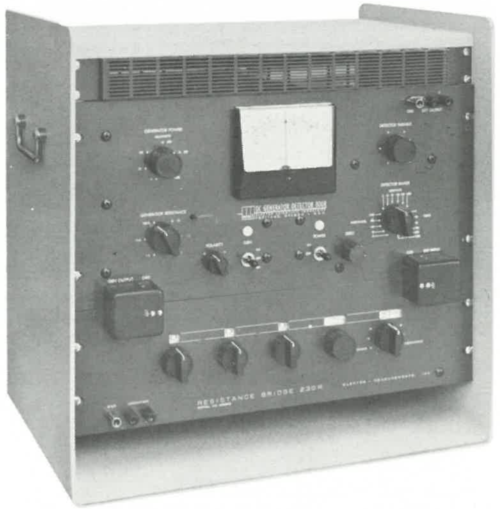
PERFORMANCE OF ESI MODEL 291-A

The resistance performance of the ESI Model 291-A Universal Impedance Bridge is shown in Figure 2. The bridge curves are for a ± (0.05% + 1 dial division) unbalance. The solid curves are for the 10-volt generator, the dotted curves represent the bridge performance with the 300-volt supply. Measurements to 1 megohm are with the resistance circuit (from 1 megohm to 100,000 megohms the conductance circuit is used). The light-beam galvanometer of this bridge has much greater sensitivity than the meter galvanometer of the Model 250 Bridge. Three different meter damping conditions are provided. Optimum damping is obtained by placing a resistance in series with the detector when the supply source has a low resistance, connecting directly to the meter when the source has the proper damping resistance and placing a resistance in parallel when the source has a high resistance. There are three sensitivity conditions and these combined with the three damping conditions result in nine combinations of detector performance. The resulting curves for 1/5 scale division on the galvanometer are drawn for the ranges that they are applicable to so that we may determine the optimum detector control settings as well as a measure of bridge performance.

For example, again measuring a 10 ohm resistor using the 10 ohm to 100 ohm range we have about 15 times as much voltage as we need for a 0.2 scale division deflection with the damping switch in position 1. By changing to damping position 2 we will have 40 times as much voltage as we need for 0.2 scale divisions but the meter will be very sluggish. By using the center sensitivity position we would only have about 70% of the 0.2 scale divisions for a 0.05% unbalance. It would take about 0.07% unbalance to give the 0.2 scale divisions.

PERFORMANCE OF ESI MODEL 231

The ESI Model 231 Guarded Wheatstone Resistance Measuring System takes advantage of modern measurement techniques to extend the range of measurable resistance values for a single instrument. The high resolution and low power dissipation required for precision resistance measurements place severe requirements on the detector capability. The sensitivity of such a bridge approaches the thermal noise level for room temperature and a one cps band width. This is about the practical limit because even a band width this narrow gives an undesirably long response time for the meter movement. The meter is calibrated in microvolts and the curve shown in Figure 3 is for a signal to noise ratio of approximately one. This occurs at about 0.2 microvolt.



MODEL 231 GUARDED WHEATSTONE RESISTANCE MEASURING SYSTEM

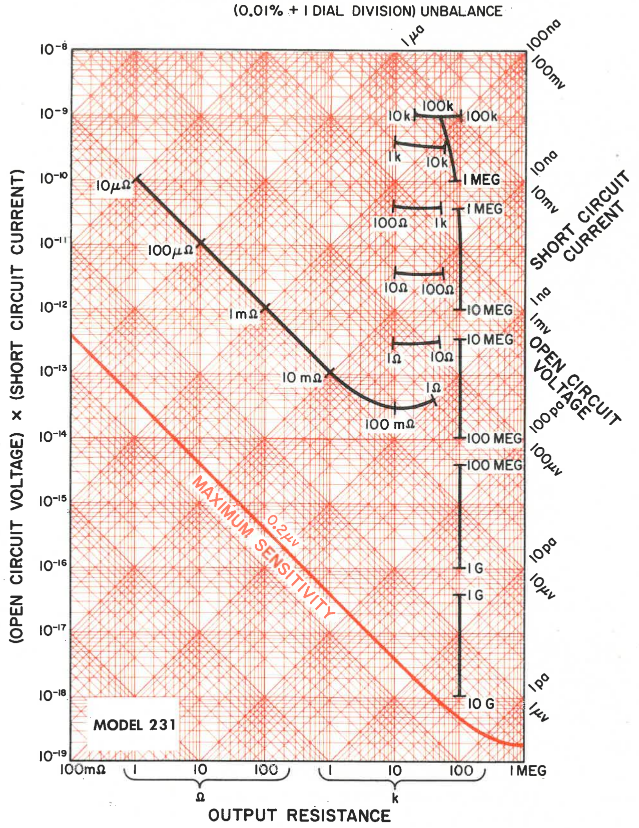
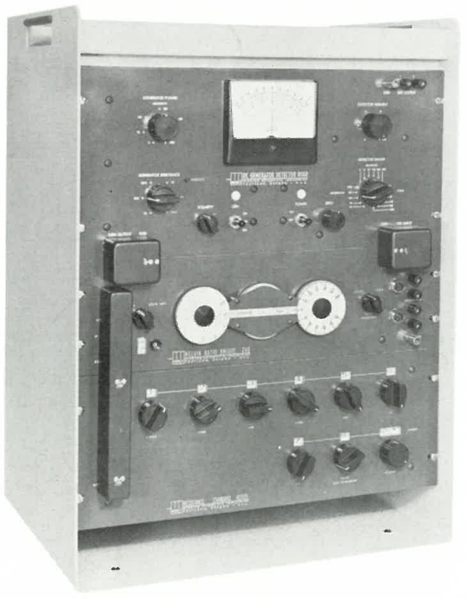


Figure 3.



MODEL 242 RESISTANCE MEASURING SYSTEM

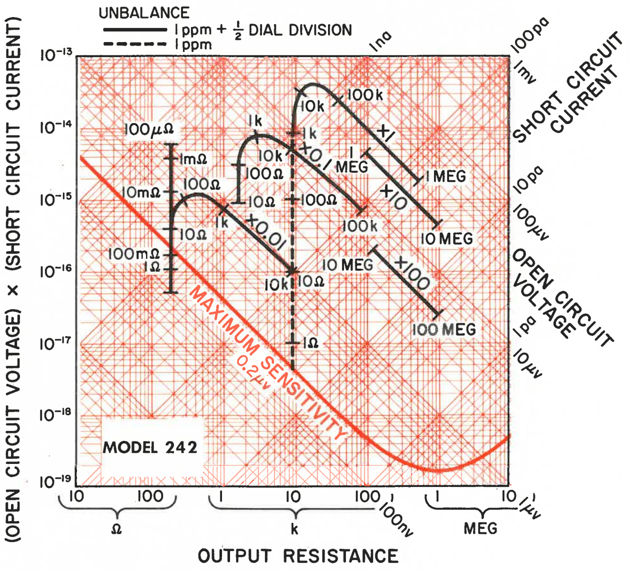


Figure 4.

PERFORMANCE OF ESI MODEL 242

The ESI Model 242 Precision Resistance Measuring System consists of a Kelvin Comparison Bridge and a Decade Resistance Standard. The curves are for an unbalance of one ppm (part per million) plus ½ of one dial division resolution on the lowest range of the Resistance Standard. These values were chosen as easily obtainable limits for simple comparison measurements.

The setting resolution of the 242 System is considerably better than 0.5 dial divisions. To separate the accuracy and resolution contributions the output of the one to one range has also been shown as a dotted curve for 1 ppm unbalance when measuring low value resistance.

DETECTOR COMPARISON

Graphs such as those in Figure 5 can be used for a comparison of detectors for such purposes as deciding which detector would be adequate for a given measurement job. The detector sensitivity can be chosen as the weakest signal which can be separated from the noise or as the smallest indicator deflection which can be determined with certainty. The detector curves for constant deflection all have the same basic shape and can be easily drawn from data such as current sensitivity, input resistance and noise, which is usually supplied by the detector manufacturer. The extensions of the straight line portions of the curve intersect at a point representing the voltage sensitivity, current sensitivity and input resistance of the detector. In very sensitive detectors, the minimum detectable signal may be limited by noise. The noise deflection may be a function of generator resistance. In this case, the curve of minimum detectable generators can be drawn from experimental data on noise versus generator resistance. Another modification of the detector curve occurs for galvanometers with series or parallel resistance added to control the galvanometer damping.

The sensitivity of ac as well as dc detectors can be plotted on this same co-ordinate system. The reactances of the generator and the detector will affect the way that an ac detector curve "turns the corner" but the straight line portions will not be greatly different from the dc curves. If the generator and detector impedances have the same angle, the plot is the same as for a dc detector. Several representative ac and dc null detectors ranging from sensitive galvanometers to a set of headphones are plotted in Figure 5 for comparison.

DRAW YOUR OWN CURVES

For those who may be interested in pursuing this method of analysis farther, ESI Engineering Bulletin, No. 23 goes into more detail about the techniques and describes the method of calculating the bridge performance curves.

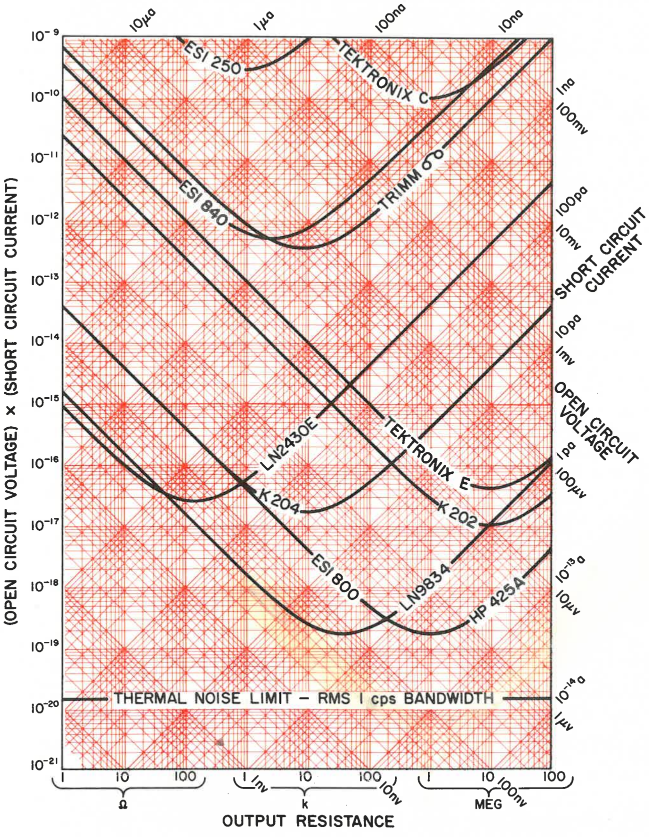


Figure 5.

Litho in U.S.A.